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(72) Inventors KENNETH CHARLES ARTHUR SMITH and JOHN RICHARD ADRIAN CLEAVER

(54) ELECTRON GUNS

(71) We, KENNETH CHARLES ARTHUR SMITH and JOHN RICHARD ADRIAN CLEAVER, both British subjects of Cambridge University Engineering Department, Trumpington Street, Cambridge, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electron guns and to instruments, such as electron probe micro- [illegible] scanning electron microscopes, and

does not take account of changes in beam current that occur actually during use.

It has also been proposed to monitor the beam current at or near the surface of the specimen on which the beam impinges, and to use this signal to modify the heater current or to correct a signal derived from the specimen, but the use of a monitoring signal derived well down the column opens the way to errors due to a change in the monitoring signal resulting from a shift in beam alignment rather than a change in beam current.

PATENTS ACT 1949

SPECIFICATION NO 1380126

Reference has been directed, in pursuance of Section 8 of the Patents Act 1949, to Specification No's 1378084 and 1375789.

THE PATENT OFFICE
29 August 1975

R 24012/1

in vacuum [illegible] combination with differential pumping of the electron gun to a higher vacuum than the remainder of the column, have largely overcome the first drawback but the second still presents serious problems.

It is known in the case of thermionic electron guns to control the heated filament, and thereby the emission of electrons, in response to a feedback signal so that the emission is kept constant. It has also been proposed in the case of thermionic guns to check the whole beam current before or after use of the instrument and to use the result to adjust the filament current and hence the beam current. However this is hardly a practical procedure for day-to-day use and anyway it

and equipped with means for monitoring the beam current of the beam of electrons passing through that hole and producing a signal which is used to control the total emission from the cathode in a manner such as to keep the said beam current substantially constant.

By measuring the beam current of the electrons passing through the hole in the anode, we ensure that it is the useful beam current that it is kept constant, regardless of the total emission. It may well be that with changes in the shape of the tip of the cathode due to erosion, the total emission has to be increased at one time to keep the beam current at the desired value, yet at another

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This invention relates to electron guns and to instruments, such as electron probe microanalysers, scanning electron microscopes, and electron beam welding equipment, which employ such guns.

The orthodox gun comprises a thermionic cathode and one or more anodes for accelerating the electrons and forming them into a beam, and these anodes may also have a focussing action on the beam, acting as a weak electrostatic lens. In the search for higher beam intensities in combination with smaller spot sizes it has been proposed over many years to use a field emission source in place of a thermionic source. However field-emission sources require a much higher vacuum (of the order of 10^{-9} Torr) than thermionic cathodes and also have contamination and erosion problems. Improvements in vacuum techniques in recent years, in combination with differential pumping of the electron gun to a higher vacuum than the remainder of the column, have largely overcome the first drawback but the second still presents serious problems.

It is known in the case of thermionic electron guns to control the heated filament, and thereby the emission of electrons, in response to a feedback signal so that the emission is kept constant. It has also been proposed in the case of thermionic guns to check the whole beam current before or after use of the instrument and to use the result to adjust the filament current and hence the beam current. However this is hardly a practical procedure for day-to-day use and anyway it does not take account of changes in beam current that occur actually during use.

It has also been proposed to monitor the beam current at or near the surface of the specimen on which the beam impinges, and to use this signal to modify the heater current or to correct a signal derived from the specimen, but the use of a monitoring signal derived well down the column opens the way to errors due to a change in the monitoring signal resulting from a shift in beam alignment rather than a change in beam current.

Moreover in the case of field emission cathodes the problem is different, as the total electron current from the cathode by no means bears a constant relationship to the useful beam current, and the ratio of total to useful current changes during use as a result of erosion causing changes in the shape of the tip from which the emission takes place.

The aim of the present invention is to improve the stability and control of the electron beam from a field emission gun. According to the invention there is proposed a field emission electron beam-forming gun comprising a field emission cathode and an anode having a hole in it through which a beam of electrons from the cathode passes, and equipped with means for monitoring the beam current of the beam of electrons passing through that hole and producing a signal which is used to control the total emission from the cathode in a manner such as to keep the said beam current substantially constant.

By measuring the beam current of the electrons passing through the hole in the anode, we ensure that it is the useful beam current that it is kept constant, regardless of the total emission. It may well be that with changes in the shape of the tip of the cathode due to erosion, the total emission has to be increased at one time to keep the beam current at the desired value, yet at another

time the total emission has to be decreased for the same purpose.

Where there are two anodes each with beam-defining apertures, the result can be obtained by insulating the second anode and monitoring the current that flows to it. This gives a measure of the electrons that have passed through the aperture in the first anode but not the second, and this value is substantially proportional to the number that do pass through the second anode and form the useful beam.

Alternatively we may monitor the electrons falling on an auxiliary electrode in the form of a ring, through which the electrons pass, between the two anodes or following the second anode or, where there is only one anode, following this anode.

The correction signal is preferably applied to a control electrode which is inserted between the cathode and the first anode, but much closer to the former than to the latter. This control electrode has a positive potential applied to it and provides the dominant influence on the potential gradient at the cathode surface, and thus on the current drawn. The tip of the cathode may be level with or protrude slightly through the aperture in the control electrode.

The invention will now be further described by way of example with reference to the accompanying drawing which is a diagrammatic illustration of a gun according to the invention and its control circuit.

The gun comprises a cathode 1 in the form of a rod terminating in a pointed tip of very small radius, in a known manner, such that the electric field gradient in the immediate neighbourhood of the tip created by a first anode 2, positive with respect to the cathode, causes electrons to be emitted by the tip without any heating. However some heat may be applied by means not shown, in which case the emission is increased and operation is in what is known as the TF mode.

Unless a field emission cathode is operated under extremely good vacuum conditions there are normally significant fluctuations in the electron emission from its surface. Electron emission from the tip takes place over a large solid angle, with the local current density at a given point depending on crystal structure, surface roughness (which changes with time due to erosion) and on contamination. The useful beam, which passes through a hole 3 in the anode 2, consists only of electrons which have been emitted from a very small portion of the tip, close to the electron beam axis A. Fluctuations in the emission at different regions of the tip are not correlated, and so the beam current is not directly related to the total current from the cathode.

The potential of the anode 2 influences the total emission and focal properties of the gun. That part which passes through the hole 3 is accelerated to the required energy by a second anode 4 in which there is a hole 5. In a typical case the first anode 2 may be between 1 and 5 kilovolts positive with respect to the cathode, and the second anode is between 20 and 50 kilovolts positive. However in other situations, where only low-energy electrons are required, the second anode might even be at a lower voltage than the first, so that it retards the electrons.

Not all the electrons passing through the hole 3 pass also through the hole 5. On the contrary some strike the second anode 4 and the resulting current in the second anode is what we use to monitor the beam current. For this purpose the second anode 4, which is insulated from a surrounding enclosure by a ceramic ring 6, is connected to a current amplifier 7. The output of this amplifier acts through an electrically insulating link, indicated at 8, on means 9 that controls the positive potential, with respect to the cathode 1, of a control electrode 10. This electrode 10 is in the form of a disc with a central hole through which the tip of the cathode linearly protrudes. It strongly influences the electric field gradient at the tip, and therefore determines the emission of the cathode. The connections are such that any decrease or increase in the useful beam current, indicated by a decrease or increase in the current to the second anode 4, causes an increase or a decrease in the emission to restore the beam current to the desired value, set by a reference voltage supplied to the amplifier 7 at 11.

The purpose of the electrically insulating cotnrol link 8 is to allow for the fact that the anode 4 is at a very different potential from the cathode 1 and control electrode 10. It may take the form of an optical path. For example the amplifier 7 may control the brightness of a lamp or a light-emitting diode, the light from which falls on a phototransistor controlling the potential on the electrode 10.

In practice, as is usual in electron guns, we put the second anode 4 at earth potential and the cathode 1 and its associated components are at a high negative potential, as indicated diagramamtically at 12.

Instead of monitoring the current in the second anode 4 we could monitor the current in a specially provided ring electrode following it, as indicated at 13 in the drawing, or between the two anodes as shown at 13[1]. In some cases there may only be one anode, in which case we would have an electrode such as 13 following that anode.

In the example shown, the hole 5 in the second anode is small enough to allow differential pumping, i.e. to allow the region, indicated at U, containing the electron gun

to be pumped out to a higher vacuum than the region V of the remainder of the instrument in which the gun is used.

It will be appreciated that by the invention we have provided a compact self-regulating constant beam-current field emission gun, in which the regulation is achieved by monitoring means, either an anode or a separate ring electrode, associated with the gun itself, sensing a signal closely dependent on the actual beam current, and not influenced by the alignment of the following electron-optical system.

We may include in the gun some heating coils 14, shown fitting in apertures in the control electrode 10. These are not operative when the instrument is in normal use but when the machine is out of use they can be connected to a source of current to heat the surface of the first anode 2 and simultaneously bombard it with electrons, so as to clean and outgas that anode. The coils 14 may also be used to regenerate the cathode, with all electrodes grounded, or a separate heater may be provided for this purpose. For the cleaning and outgassing function, in place of the fixed coils 14 mounted in the control electrode 10, we could use a coil mounted on a swinging arm and capable of being brought into a position between the electrode 10 and the first anode 2, or between the first and second anodes 2 and 4.

In addition to monitoring the beam current we preferably also monitor the total emission of the cathode and arrange to shut the gun down when the emission exceeds a predetermined value. This is because the emission increases with time, due to damage caused by spluttering, and the effect is cumulative, so that eventually the cathode is destroyed. The total emission can be satisfactorily monitored by measuring the current flow to the first anode 2, which intercepts all but a fairly small fraction of it.

Alternative forms for the insulating link 8 include a transformer or a capacitor, if the error signal is modulated onto an alternating current carrier or is in pulse coded form.

WHAT WE CLAIM IS:—

1. A field emission electron beam-forming gun comprising a field emission cathode and an anode having a hole in it through which a beam of electrons from the cathode passes, and equipped with means for monitoring the beam current of the beam of electrons passing through the hole, and producing a signal which is used to control the total emission from the cathode in a manner such as to keep the said beam current substantially constant.

2. A gun according to claim 1 in which the monitoring means comprises means sensing the current in an insulated second anode, following the first-mentioned anode, this second anode having a hole in it through which pas those of the said beam of electrons that form the useful beam.

3. A gun according to claim 1 in which the monitoring means comprise means sensing the current in a ring electrode following the anode and surrounding the path of the electrons through the hole.

4. A gun according to claim 3 including a second anode between the first anode and the ring electrode.

5. A gun according to any one of claims 1 to 4 in which the signal acts on a control electrode influencing the electric potential gradient in the immediate vicinity of the cathode.

6. A gun according to claim 5 in which the control electrode is a disc with a hole in which an emissive tip of the cathode lies.

7. A field emission gun arranged and operating substantially as described with reference to the accompanying drawing.

BARKER, BRETTELL & DUNCAN,
Agents for the Applicants,
Chartered Patent Agents,
16, Greenfield Crescent,
Edgbaston,
Birmingham, B15 3BA.

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1380126 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*